Outcomes assessment of lunate replacement arthroplasty with intrinsic carpal ligament reconstruction in Kienböck's disease

Mark Henry

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Abstract

Background With advanced Kienböck's disease, hyaline cartilage delamination or bone fragmentation render the lunate unsalvageable. Common surgical options are proximal row carpectomy, scaphotrapeziotrapezoid fusion, scaphocapitate fusion, or total wrist fusion. The purpose of this study was to prospectively evaluate the clinical and radiographic outcomes of one alternative: lunate prosthetic replacement arthroplasty combined with reconstruction of the scapholunate and lunotriquetral interosseous ligaments using the flexor carpi radialis tendon.

Methods Eligible patients with advanced Kienböck's disease and an unsalvageable lunate were included in this prospective study on a self-selected basis, forming a study group of 13 consecutive patients, 6 males and 7 females with a mean age of 40. Clinical and radiographic measurements were compared at a mean follow-up of 30.3 months from surgery with a paired, single-tailed, Student's *t* test using a *p* value of 0.05 as statistically significant.

Results Mean preoperative/postoperative clinical measurements were as follows: wrist flexion 29.2°/43.3°, wrist extension 24.2°/53.3°, absolute value grip strength 12.3/31.5 kg, grip strength vs. contralateral 36.5/85.2 %, and DASH scores 39.1/7.7. Mean initial/immediate postoperative/final radiographic measurements were the following: scapholunate angle 64.2°/46.7°/46.4°, radioscapoid angle 64.6°/42.1°/45°, and modified carpal height ratio 1.20/1.62/1.59. Preoperative to postoperative differences were all statistically significant.

Conclusions Although these subjective and objective results reflect substantial improvement, there remain recognizable

deficiencies in both prosthetic design and surgical strategy that require further modification.

Keywords Lunate · Arthroplasty · Kienböck's · Ligament · Reconstruction

Introduction

Avascular necrosis of the lunate, Kienböck's disease, can ultimately progress to complete collapse and fragmentation, rendering the lunate unsalvageable. Natural history studies of early-stage Kienböck's disease (Stahl/Lichtman stages I and II) do not indicate that progression to higher stages is a certainty or that intervention during the early stages necessarily changes the final outcome [14, 15, 24, 28, 29, 31, 33]. Once collapse has begun (Stahl/Lichtman stages IIIA/IIIB), progression to further collapse and eventual fragmentation is expected [25, 27]. Magnetic resonance imaging (MRI) is frequently used in early-stage disease to confirm the diagnosis when plain radiographs are equivocal. MRI offers little help in prognosis and treatment planning. The most commonly used Stahl/Lichtman classification scheme is based on plain radiographs and does not distinguish a lunate that can be salvaged from one that cannot. Many stage IIIB lunates can be salvaged with vascularized bone grafting, avoiding irreversible anatomic modification of wrist structure [9, 17, 20]. There are two distinguishing features that identify an unsalvageable lunate; both are best delineated on computed tomography (CT) scan. A lunate cannot be salvaged if the hyaline cartilage has delaminated from the underlying subchondral bone, or if the lunate has already fragmented into multiple pieces. Our center classifies Kienböck's into three groups: early disease (MRI changes, no collapse), progressive disease (collapse occurring on plain radiographs, salvageable by CT scan), and unsalvageable (fragmentation or delamination on CT scan). For early

M. Henry (✉)
Hand and Wrist Center of Houston, 1200 Binz Street, 13th Floor,
Houston, TX 77004, USA
e-mail: mhenry@houstonhand.com

disease, patients are instructed on the literature regarding natural history and may choose from observation vs. revascularization (direct or indirect) on an individual basis [1, 2, 6, 30]. With progressive collapse, most patients choose direct revascularization with a pedicled bone flap over indirect revascularization by core decompression/osteotomy [10, 13, 22]. For an unsalvageable lunate, patients are instructed that the standard surgical options are proximal row carpectomy (PRC), scaphotrapeziotrapezoid (STT) fusion, scaphocapitate (SC) fusion, or total wrist fusion (TWF) [5, 7, 8, 16, 18, 26, 32]. Many patients have already interviewed with surgeons and researched these options on their own. Some patients have refused to undergo any of these options and seek an alternative. The purpose of this study was to prospectively evaluate the clinical and radiographic outcomes of a consecutive series of patients receiving prosthetic lunate replacement with reconstruction of the scapholunate (SLIL) and lunotriquetral (LTIL) interosseous ligaments.

Materials and Methods

In preparation for study eligibility, adult patients presenting with advanced Kienböck's disease and a CT scan demonstrating an unsalvageable lunate (based on bone fragmentation and/or hyaline cartilage delamination from underlying subchondral bone) were given a complete education on Kienböck's disease and its treatment options. Patients were told that the standard options include PRC, STT fusion, SC fusion, or TWF. Those patients that found one of the standard options acceptable were treated with their chosen procedure and excluded from this study on that basis. Other exclusion criteria included inflammatory joint disease, diabetes, or medical comorbidities rendering the patient unsuitable for general anesthesia and reconstructive joint surgery. Eligible patients who did not find one of the standard treatments acceptable and specifically inquired about additional options were told that prosthetic replacement of the lunate is possible but without any known long-term results. The added complexity of intrinsic carpal instability was explained, including strong emphasis that loss of scapholunate and lunotriquetral integrity in a patient with a normal lunate is a complex wrist surgery problem that has yet to find a definitive solution. Patients were only offered inclusion in this prospective study (approved before inception by the institutional review board) if they distinctly preferred prosthetic arthroplasty and ligament reconstruction to the standard treatments despite the detracting features of carpal instability and unknown long-term results. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed written consent was obtained from all patients for being included in the study.

Thirteen consecutive patients (seven females, six males, mean age 40) chose to participate in the study and undergo lunate prosthetic replacement arthroplasty (Integra, Plainsboro, NJ, USA) combined with reconstruction of the SLIL and LTIL using the flexor carpi radialis (FCR) tendon (Table 1). Surgery was performed according to a previously published technique (Fig. 1) [11]. In brief, after excising the necrotic lunate through the primary dorsal wrist wound, trial prostheses are inserted in the lunate gap to determine the correct size (five possible sizes). The lunate prostheses are manufactured in the same manner as the other pyrocarbon prostheses familiar to hand surgeons. In the sagittal plane, the distal surface is concave and the proximal surface convex. The scaphoid facet on the radial side is smaller than the triquetral facet on the ulnar side. Two transverse passages in the coronal plane (one volar, one dorsal) connect the scaphoid with the triquetral facets through the body of the prosthesis. A 3-mm strip of FCR tendon is harvested from two small volar wounds and used to stabilize the proximal row. The FCR maintains its distal attachment, passes through the scaphoid, the dorsal hole in the prosthesis, the triquetrum, the volar hole in the prosthesis, and back to the scaphoid to simulate the volar and dorsal limbs of the SLIL and LTIL. A single 0.062-in. K-wire is placed from the radius through the scaphoid to the capitate to control carpal position and then removed between 4 and 6 weeks in the office during a cast change. Patients are immobilized for 8 weeks total (splint for 2 weeks then cast for six additional weeks) and then advanced through a progressive motion and strengthening rehabilitation program, adapted from scapholunate reconstruction. Preoperative to postoperative measures were compared at a mean follow-up of 30.3 months from surgery with a paired, single-tailed, Student's *t* test using a *p* value of 0.05 as statistically significant for wrist flexion (degrees); wrist extension (degrees); absolute value grip strength (kg); grip strength vs.

Table 1 Patient demographics

Patient	Age (years)	Sex	Hand dominance	Follow-up (months)
1	24	F	Nondominant	34
2	38	M	Dominant	32
3	28	M	Dominant	48
4	43	M	Nondominant	38
5	28	F	Nondominant	27
6	32	F	Dominant	28
7	30	F	Dominant	43
8	36	F	Dominant	43
9	66	F	Nondominant	43
10	41	F	Nondominant	13
11	55	M	Nondominant	16
12	50	M	Nondominant	14
13	50	M	Nondominant	15

Fig. 1 **a** Posteroanterior and **b** lateral radiographs. Note the parallel alignment of the distal surface of the capitate and distal surface of the lunate implant

contralateral (percent); Disabilities of the Arm, Shoulder and Hand (DASH) scores; scapholunate angle (degrees); radioscaphoid angle (degrees); and modified carpal height ratio (Table 2).

Results

Mean preoperative/postoperative clinical measurements were as follows: wrist flexion 29.2° (SD 10.1)/43.3° (SD 18.8), wrist extension 24.2° (SD 13.2)/53.3° (SD 14.9), absolute value grip strength 12.3 kg (SD 4.9)/31.5 kg (SD 8.34), grip strength vs. contralateral 36.5 % (SD 8.4)/85.2 % (SD 7.8), and DASH scores 39.1 (SD 14.2)/7.7 (SD 3.6) (Table 2). All differences were statistically significant; the highest *p* value of 0.018 was for wrist flexion. Mean initial/immediate postoperative/final radiographic measurements were the following: scapholunate angle 64.2° (SD 12.4)/46.7° (SD 6.2)/46.4° (SD 6.7), radioscaphoid angle 64.6° (SD 10.5)/42.1° (SD 5.4)/45° (SD 4.5), and modified carpal height ratio 1.20 (SD 0.05)/1.62 (SD 0.04)/1.59 (SD 0.06). All differences were statistically significant; the highest *p* value of 0.0016 was for the scapholunate angle.

In one patient (# 10), achieving sagittal plane balance of the prosthesis proved impossible and the case was converted to a proximal row carpectomy. One patient (# 11) ignored his written instructions, removed his splint, and started moving his wrist the first week after surgery, experienced migration of the stabilizing K-wire, and required reoperation to replace it. One patient (# 13) demonstrated features of avascular necrosis in the proximal pole of the scaphoid at 9 months postoperatively and was ultimately revised to a proximal row

carpectomy. All patients were included in the study and data analyzed on an intent-to-treat basis. There were no cases of wound infection, prosthetic dislocation, or prosthetic erosion.

Discussion

Kienböck's disease is an unfortunate diagnosis at any stage but particularly problematic when the lunate is unsalvageable. None of the options available at this point are ideal, including the method described in this series [19, 21]. Total wrist fusion has the obvious detriment of sacrificing all motion but with the advantage of a reliable and consistent result. Limited wrist fusions, STT and SC, create an incongruent articulation with load concentration between the scaphoid and radius which limits motion and wears out over time [26, 32]. Fifty-nine patients surveyed at 4 years postoperatively only achieved a total arc of flexion-extension motion of 67° (60 % contralateral), radioulnar deviation motion arc of 31° (52 % contralateral), and a mean DASH score of 28 [18]. Proximal row carpectomy also creates an incongruent articulation with load concentration between the capitate and radius which wears out over time [5, 21]. Twenty-one patients, with a mean age of 39 years at the time of surgery, only achieved a total arc of motion of 76°, 65 % of contralateral grip strength, and a mean DASH score of 22, and by 5.5 years, 8/21 already had moderate to severe pain [7].

The theoretical benefits of lunate prosthetic replacement are more normal joint kinematics and the creation of a more congruent articulation with wider load distribution compared to STT/SC fusion or PRC, albeit with a foreign material. Pyrocarbon's unique properties are favorable for this task with

Table 2 Initial, postoperative, and final objective measurements

Patient	1	2	3	4	5	6	7	8	9	10	11	12	13
I-WF	30	20	40	40	30	35	10	40	20	30	15	40	30
F-WF	55	50	60	50	65	25	10	15	35	45	60	35	60
I-WE	30	10	40	30	0	35	5	40	20	30	15	35	25
F-WE	65	50	70	50	70	25	30	70	50	50	60	45	55
I-GS	11	15	23	18	8	14	8	16	4	10	10	11	12
F-GS	25	40	45	38	33	20	27	25	20	30	40	40	27
I-%CL	36	42	50	35	40	45	30	46	25	28	22	38	38
F-%CL	90	90	90	78	90	75	85	83	100	70	82	90	85
I-DASH	44	39	28	27	36	45	51	22	72	42	52	29	22
F-DASH	6	3	5	2	7	12	10	7	4	10	12	11	12
I-SLA	40	75	75	70	70	65	50	50	50	65	75	75	75
P-SLA	50	55	45	40	45	40	35	55	50	N/A	45	50	50
F-SLA	50	50	50	40	45	45	30	55	50	N/A	45	50	N/A
I-RSA	50	75	60	80	70	60	60	50	50	70	75	65	75
P-RSA	40	50	35	50	35	40	40	40	40	N/A	45	40	50
F-RSA	40	50	40	50	45	50	50	40	45	N/A	45	40	N/A
I-MCH	1.12	1.25	1.28	1.16	1.21	1.12	1.24	1.2	1.14	1.21	1.18	1.21	1.23
P-MCH	1.64	1.66	1.59	1.61	1.55	1.54	1.6	1.65	1.63	N/A	1.63	1.66	1.66
F-MCH	1.56	1.67	1.6	1.55	1.54	1.45	1.6	1.6	1.63	N/A	1.61	1.67	N/A

I initial (preoperative), *P* postoperative (immediately), *F* final (last follow-up), *WF* wrist flexion (degrees), *WE* wrist extension (degrees), *GS* grip strength (kg), *%CL* percentage of contralateral grip strength, *DASH* Disabilities of the Arm, Shoulder and Hand score, *SLA* scapholunate angle from lateral radiograph, *RSA* radioscapoid angle from lateral radiograph, *MCH* modified carpal height ratio (base of the third metacarpal to the radius/length of capitate) from posteroanterior radiograph

low friction that does not create substantial particulate wear and a Young's modulus close to bone [3, 4, 23]. Despite the laudable properties of pyrocarbon, the act of replacing the lunate still leaves a major problem, complete intrinsic ligament instability of the wrist. Even with an anatomically normal lunate, loss of SLIL and LTIL integrity poses a major challenge for hand and wrist surgeons. Combined with a prosthetic lunate to which no tendon or ligament graft can attach, the challenge is even greater. The initial surgical method reported in this series (first-generation technique) attempted to take advantage of the two passages through the body of the prosthesis in the coronal plane. Clearly, no direct bond would be established between the prosthesis and the FCR graft directed from the scaphoid to the triquetrum and back to the scaphoid. But, the expectation was that the FCR graft's dorsal and volar limbs would simulate the stabilizing effects of the dorsal and volar limbs of the former SLIL and LTIL. Although the static radiographic measurements obtained during this study are satisfactory, careful direct patient examination under motion and stress (including fluoroscopic examination) reveals that the first-generation ligament reconstruction strategy is insufficient to restore actual intercarpal stability. The passages in the prosthesis are too close to each other and too close to the axis of rotation to effectively control the sagittal plane balance of the prosthesis. The manufacturer

states it currently has no plans to alter the design of the prosthesis despite surgeon feedback. Any further clinical progress with this prosthesis will have to work around the shortcomings of its design.

Given the inability to directly control the position of the lunate prosthesis, the second-generation surgical technique now in use (subsequent to the patients reported in this study) has been modified to focus on better indirect control of the prosthetic balance by improving direct control over the scaphoid-to-triquetrum relationship. The revised strategy intentionally bypasses the prosthesis with the FCR graft, stabilizing the scaphoid directly to the triquetrum and back to the scaphoid, adapted from a technique for carpal instability reconstruction [12]. The graft routing over the external surfaces of the carpal bones more closely replicates the native SLIL and LTIL and increases the moment arm in the sagittal plane. The FCR graft is directly locked to the triquetrum with an interference screw (after the initial dorsal limb crosses from the scaphoid) to prevent loosening distributed along the entire length of the graft. The second-generation technique also requires only a single passage through each carpal bone and no passage through the proximal pole of the scaphoid, where avascular necrosis was found in one patient (# 13) of this study treated according to the first-generation technique.

Advanced Kienböck's with an unsalvageable lunate due to fragmentation or delamination is a difficult clinical problem for which a good solution does not exist. The traditional strategies each has detracting features which some patients are unwilling to accept. Lunate prosthetic replacement also has many detracting features but represents a different approach that some patients find more palatable. Prosthetic replacement can be revised to any of the other traditional approaches, but the same is not true in the opposite direction. Although the patients in this study were subjectively very satisfied and objectively improved, the finer details observed during the tracking of these cases pointed out the deficiencies in the first-generation approach. Adjustments have been made and research is ongoing, with long-term follow-up necessary before drawing any firm conclusions.

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Statement of Human and Animal Rights Prior to commencing, the prospective study was approved by the responsible IRB committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000 and 2008. Each patient in the study completed a specific informed consent for research participation.

Statement of Informed Consent No identifying information appears with respect to the patients in this study. Nevertheless, each patient has given express written consent for participation in the study as well as inclusion of his/her medical information for publication.

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